# Some Novel Definitions Of Fractional Order Calculus

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# DEDICATION

This text is dedicated to the all compassionate *Creator* of the *Universe* and *Goddess Sri Chakra Bandhini Devi,* a form of *Goddess Maha Kalika Devi* who ensures that the immaculate and holy one receives the full fruits of his hard work.

# CONTENTS

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# 1 INTRODUCTION

Since the discovery of Calculus by Sir Isaac Newton and professor Leibniz, there has been little progress in the domain of Fractional Order Calculus. There has been some progress in this regard but it is very cumbersome and computation intensive and also not totally holistic. Understanding Calculus at Fractional Orders is very essential as many phenomena of the Universe may be holistically explainable using Fractional Order Calculus. In this research manuscript book, the author has presented some novel definitions of Fractional Derivative, Fractional Integral, Functional Derivative, Functional Integral and Holistic Maximas & Minimas Of A Function Based On Its Domain.

# 2 SOME NOVEL DEFINITIONS OF FRACTIONAL ORDER DERIVATIVE

The following novel definitions basically capture the essence of a Fractional Derivative:

*Definition 1*

Given a function $f(x)$ continuous and differentiable at least $(N+1)$ number of times, we write

$$f^{(N+\alpha)}(x) = \lim_{\Delta x \to 0}\left\{\frac{f^{N}(x+(\alpha)\Delta x) - f^{N}(x)}{\Delta x}\right\} \quad \textit{Equation 2. 1}$$

where $0<\alpha<1$, $N$ is a Positive Integer and $f^{N}(x)$ denotes $N^{th}$ Derivative of $f(x)$ and $f^{(N+\alpha)}(x)$ denotes $(N+\alpha)^{th}$ Derivative of $f(x)$.

*Definition 2*

Given a function $f(x)$ continuous and differentiable at least $(N+1)$ number of times, we write

$$f^{(N+\alpha)}(x) = \lim_{\Delta x \to 0}\left\{\frac{f^{N}\left(x+\left\{\frac{f^{N}(x=\alpha)}{f^{N}(x=1)}\right\}\Delta x\right) - f^{N}(x)}{\left\{\frac{f^{N}(x=1)}{f^{N}(x=1)}\right\}\Delta x}\right\}$$

*Equation 2.2*

where $0<\alpha<1$, $N$ is a Positive Integer and $f^{N}(x)$ denotes $N^{th}$

Derivative of $f(x)$ and $f^{(N+\alpha)}(x)$ denotes $(N+\alpha)^{th}$ Derivative of $f(x)$.

*Definition 3*

Given a function $f(x)$ continuous and differentiable at least $(N+1)$ number of times, we write

$$f^{(N+\alpha)}(x) = \underset{\Delta x \to 0}{Lim} \left\{ \frac{f^N\left( x + \left\{ \frac{f(x=\alpha)}{f(x=1)} \right\} \Delta x \right) - f^N(x)}{\left\{ \frac{f(x=1)}{f(x=1)} \right\} \Delta x} \right\} \quad \textit{Equation 2.3}$$

where $0 < \alpha < 1$, $N$ is a Positive Integer and $f^N(x)$ denotes $N^{th}$ Derivative of $f(x)$ and $f^{(N+\alpha)}(x)$ denotes $(N+\alpha)^{th}$ Derivative of $f(x)$.

*Definition 4*

Given a function $f(x)$ continuous and differentiable at least $(N+1)$ number of times, we write

$$f^{(N+\alpha)}(x) = \underset{\Delta x \to 0}{Lim} \left\{ \frac{f^N\left( x + \left\{ \frac{f^{(N+\alpha)}(x=\alpha)}{f^{(N+\alpha)}(x=1)} \right\} \Delta x \right) - f^N(x)}{\left\{ \frac{f^{(N+\alpha)}(x=1)}{f^{(N+\alpha)}(x=1)} \right\} \Delta x} \right\}$$

*Equation 2.4*

where $0 < \alpha < 1$, $N$ is a Positive Integer and $f^N(x)$ denotes $N^{th}$

Derivative of $f(x)$ and $f^{(N+\alpha)}(x)$ denotes $(N+\alpha)^{th}$ Derivative of $f(x)$, wherein we recursively solve for $f^{(N+\alpha)}(x)$ from the above relation.

# 3 SOME NOVEL DEFINITIONS OF FRACTIONAL ORDER INTEGRAL

The following novel definitions basically capture the essence of a Fractional Integral:

The general Riemann (Definite) Integral is given by

$$\int_a^b f(x)dx = \lim_{n\to\infty} \sum_{i=1}^{n} \left\{ \left\{ \frac{b-a}{n} \right\} \{ f(x) \} \right\} \qquad \textit{Equation 3.1}$$

where $dx = \left\{ \frac{b-a}{n} \right\}$

*The General Governing Expression For A Fractional Integral*

Along the same lines of the Riemann Integral we can write the expression for a Definite Fractional Integral as follows:

$$\int_a^b f(x)d^{(N+\alpha)}x = \underbrace{\int_a^b \int_a^b \int_a^b \cdots\cdots \int_a^b \int_a^b}_{N\ times} \int_a^b f(x)d^{\alpha}x \qquad \textit{Equation 3.2}$$

where

$$\int_a^b f(x)d^{\alpha}x = \lim_{n\to\infty} \sum_{i=1}^{m} \left\{ \alpha_D \left\{ \frac{b-a}{n} \right\} \{ f(a + i(\alpha_N dx)) \} \right\}$$

*Equation 3.3*

In the Riemann Integral, for $(b-a)$, we have the $dx$ given by

$$dx = \left( \frac{b-a}{n} \right) \qquad \textit{Equation 3.4}$$

Therefore, for $(x-a)$, we have the $dx$ given by

$$dx = \left(\frac{x-a}{b-a}\right)\left(\frac{b-a}{m}\right) = \left(\frac{x-a}{m}\right) \quad \textit{Equation 3.5}$$

where $m$ is given by

$$m = \left(\frac{x-a}{n/\alpha_N}\right) \quad \textit{Equation 3.6}$$

Or rather

$$m = \left\lfloor \frac{x-a}{n/\alpha_N} \right\rfloor \quad \textit{Equation 3.7}$$

the Nearest Integer on the Lower Side, when

$$\left\{\left(\frac{x-a}{n/\alpha_N}\right) - k\right\} < 0.5 \quad \textit{Equation 3.8}$$

where $k$ is the Highest Possible Positive Integer such that $\left\{\left(\frac{x-a}{n/\alpha_N}\right) - k\right\}$ is Positive.

Or else,

$$m = \left\lceil \frac{x-a}{n/\alpha_N} \right\rceil \quad \textit{Equation 3.9}$$

the Nearest Integer on the Lower Side, when

$$\left\{\left(\frac{x-a}{n/\alpha_N}\right) - k\right\} > 0.5 \quad \textit{Equation 3.10}$$

where $k$ is the Highest Possible Positive Integer such that $\left\{\left(\frac{x-a}{n/\alpha_N}\right) - k\right\}$ is Positive.

*Definition 1*

Here, for the setup of the above section, we have

$$\alpha_N = \alpha \quad \textit{Equation 3.11}$$

and

$$\alpha_D = 1 \quad \textit{Equation 3.12}$$

*Definition 2*

Here, for the setup of the above section, we have

$$\alpha_N = \frac{\left\{\int_a^b \{f(x=\alpha)\} d^N x\right\}}{\left\{\int_a^b \{f(x=1)\} d^N x\right\}} \quad \textit{Equation 3.13}$$

and

$$\alpha_D = \frac{\left\{\int_a^b f(x=1) d^N x\right\}}{\left\{\int_a^b f(x=1) d^N x\right\}} = 1 \quad \textit{Equation 3.14}$$

*Definition 3*

Here, for the setup of the above section, we have

$$\alpha_N = \frac{\{f(x=\alpha)\}}{\{f(x=1)\}} \quad \textit{Equation 3.15}$$

and

$$\alpha_D = \frac{\{f(x=1)\}}{\{f(x=1)\}} = 1 \quad \textit{Equation 3.16}$$

*Definition 4*

Here, for the setup of the above section, we have

$$\alpha_N = \frac{\left\{\int_a^b \{f(x=\alpha)\} d^{(N+\alpha)}x\right\}}{\left\{\int_a^b \{f(x=1)\} d^{(N+\alpha)}x\right\}} \quad \textit{Equation 3.17}$$

and

$$\alpha_D = \frac{\left\{\int_a^b \{f(x=1)\} d^{(N+\alpha)}x\right\}}{\left\{\int_a^b \{f(x=1)\} d^{(N+\alpha)}x\right\}} = 1 \quad \textit{Equation 3.18}$$

wherein, we recursively solve for $\int_a^b f^{(N+\alpha)}(x)$ from the above relation.

*Definition 5*

Here, for the setup of the above section, we have

$$\alpha_N = \frac{\left\{\int_a^b \{f(x=\alpha)\} d^{\alpha}x\right\}}{\left\{\int_a^b \{f(x=1)\} d^{\alpha}x\right\}} \quad \textit{Equation 3.19}$$

and

$$\alpha_D = \frac{\left\{\int_a^b \{f(x=1)\} d^{\alpha}x\right\}}{\left\{\int_a^b \{f(x=1)\} d^{\alpha}x\right\}} = 1 \quad \textit{Equation 3.20}$$

*Definition 6*

Here, for the setup of the above section, we have

$$\alpha_N = \frac{\left\{\int_a^b \{f(x=\alpha)\} dx\right\}}{\left\{\int_a^b \{f(x=1)\} dx\right\}} \quad \textit{Equation 3.21}$$

and

$$\alpha_D = \frac{\left\{\int_a^b \{f(x=1)\}dx\right\}}{\left\{\int_a^b \{f(x=1)\}dx\right\}} = 1 \quad \textit{Equation 3.22}$$

# 3 THE NOTION OF A FRACTIONAL ORDER FUNCTIONAL DERIVATIVE AND FRACTIONAL ORDER FUNCTIONAL INTEGRAL

*The Functional Fractional Derivative*

Here, we consider Derivative of the kind

$f^{g(x)}(x)$ where, the Fractional Derivative is computed along the values taken by the function $g(x)$.

*The Functional Fractional Integral*

Here, we consider Integral of the kind

$\int f(x)d^{h(x)}x$ where, the Fractional Inegral is computed along the values taken by the function $g(x)$.

# 4 MAXIMAS AND MINIMAS OF A FUNCTION BASED ON ITS DOMAIN

For a given function $f(x)$ with a Domain, say, $[u,v]$, we can find taken by the function $f^k(x)$ where $k$ is a Real Positive Integer given by $k = i\delta$ where $i = 0,1,2,3,.....$ and $0 < \delta < 1$ is the Least Count of $k$ for numerical computation of the Fractional Derivative of concern here. We now plot $f^k(x)$ for all the values of $i = 0,1,2,3,.....$ up to a certain limit for a given value of $x$. We now also plot $f^k(x)$ for all the values of $x = [u,v]$ as we vary $k$, i.e., for each $k$. This gives us a family of curves of $f^k(x)$, one for each $k$ value. From these curves, we can find where the function $f^k(x)$ actually assumes the Maximas and Minimas for a given $k$ value. As a matter of fact, we can find the entire list of Maximas and Minimas for all the values of $k$ considered here within the bounds $x = [u,v]$. Knowing these curves is of great importance because in the problems of Rate Changing Functions such as Change of Momentum and Mass of a Rocket in motion, we can Optimize Momentum gain and Fuel Consumed by the Rocket given the colloquial nature of such Rate Change functions of concern. As a matter of fact, even when colloquial quantifications of such aforementioned Rate Change Functions are not known clearly enough, we can recursively find them using the data of observations of such aforementioned Rate Change Parameters.

Also, these curves can be advantageously used for Optimal Explaining Of Rate Kinetics Of Chemical Reactions, also the Optimal Phase

Transition Design in Material Science Engineering Problems. Also, these curves can be used advantageously for Optimal Engineering Turbine Design by simultaneous optimization of the Turbine Design Parameters. Furthermore, these family of curves also find use in Optimization of Design Of Nuclear Fission, Fusion Rates and consequential Optimal Nuclear Reaction Moderation Design.

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*Comments*

The Notation used in the book is self-explanatory and is usually, Chapter inclusive only.

It is also to be noted that the entire research work of this book is wholly (each and every line of this research manuscript) authored by the author himself, i.e., his primary consciousness, and the author has not invited any other life entities of any kind in the participation of authoring of this book and consequently does not accord the consent of ownership of his intellectual property to any such claimants.

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